CHANGING WHAT'S POSSIBLE

Long duration storage: metrics and technologies

ARPA-E Workshop

December 7 and 8, 2017

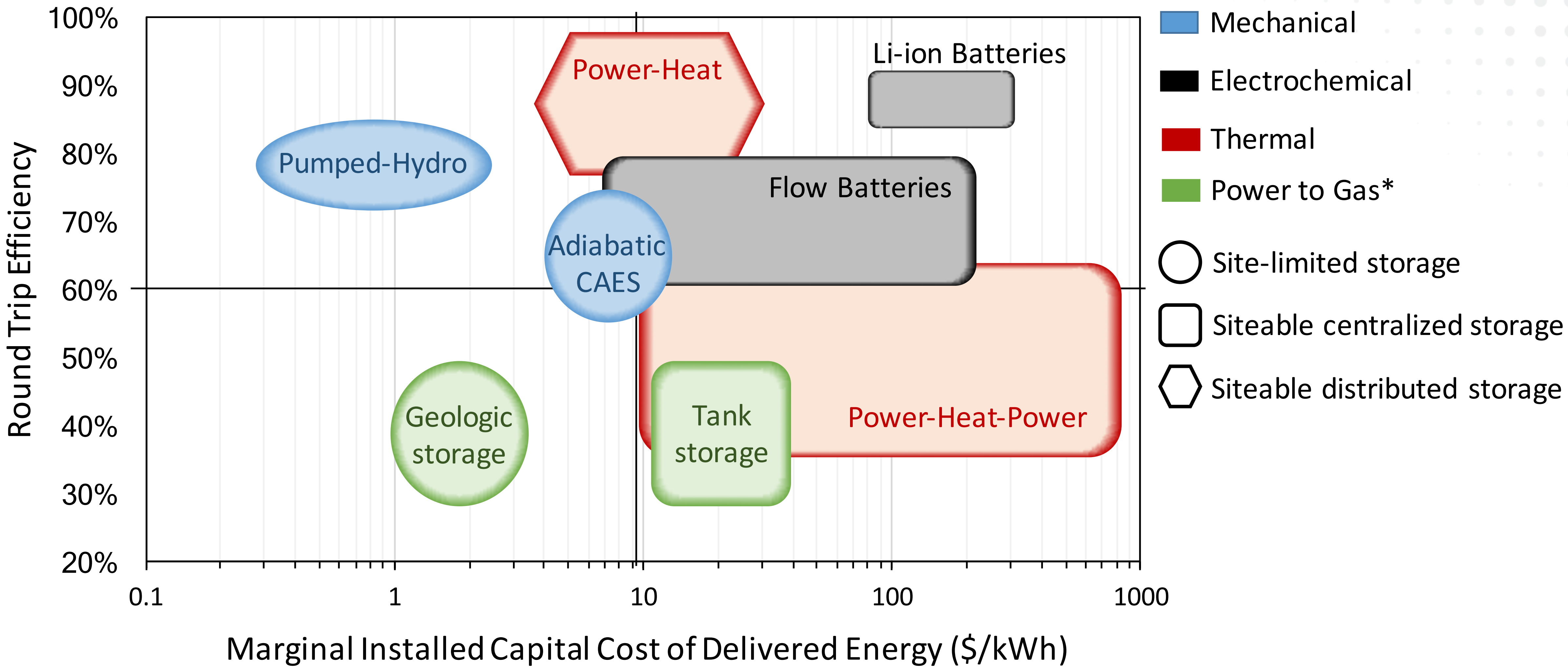
Outline

- **Focus areas for this potential program**
- Economics of long-duration storage, and proposed cost targets
- Implications of the cost target for system design
- Technical approaches

What's in focus for this potential program

- Electrical input. Electrical *or* thermal (at building conditions) output.
  No chemical outputs for use in other applications (*e.g.*, hydrogen for hydrocracking)
- Durations of 8 to ~50 hours.
- Total installed capital costs of 2 to 100 $/kWh.
- Systems that are location independent.
- Ideal *per-cycle* costs of ~0.03 $/kWh-cycle regardless of cycles/year.
- Round-trip efficiency of >50%, preferably higher.
- System size of at least 100 kW. 10s to 100s of MW is of interest.

Technologies of interest in roundtrip efficiency context



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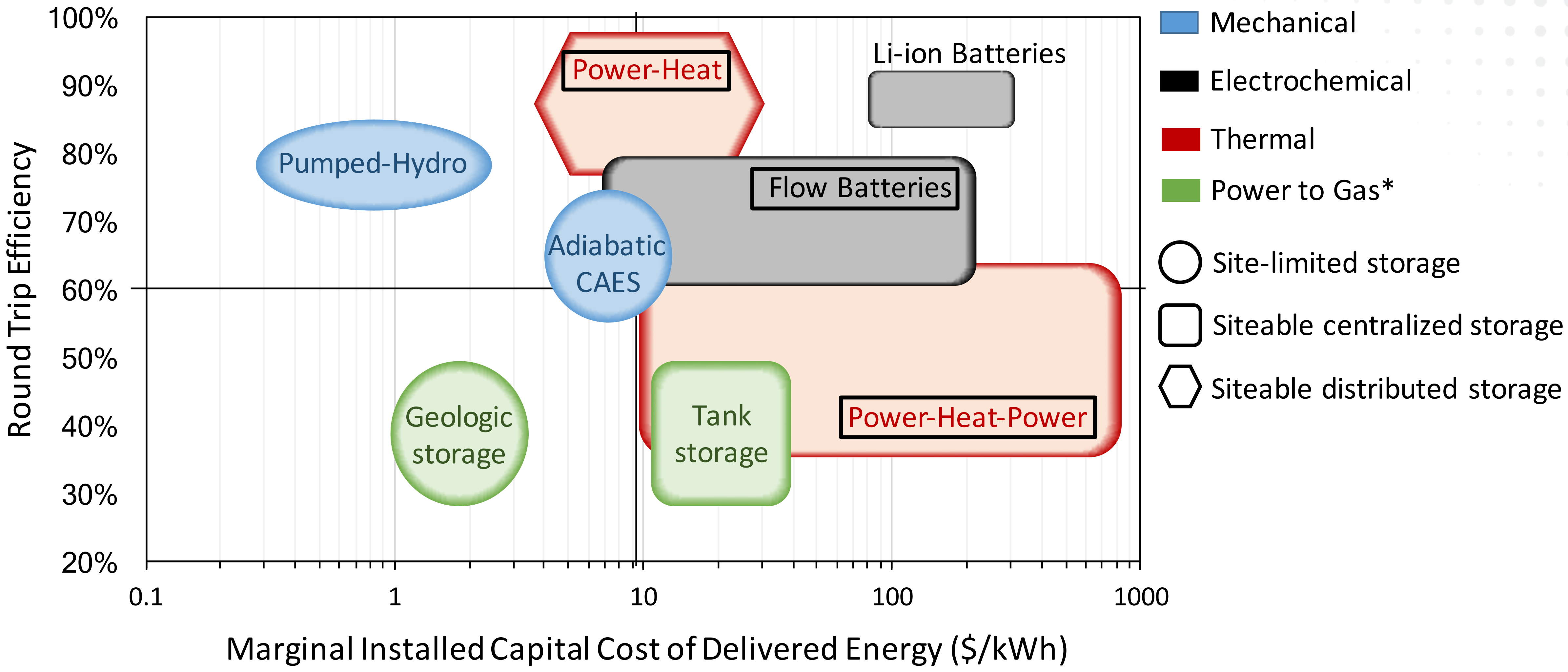
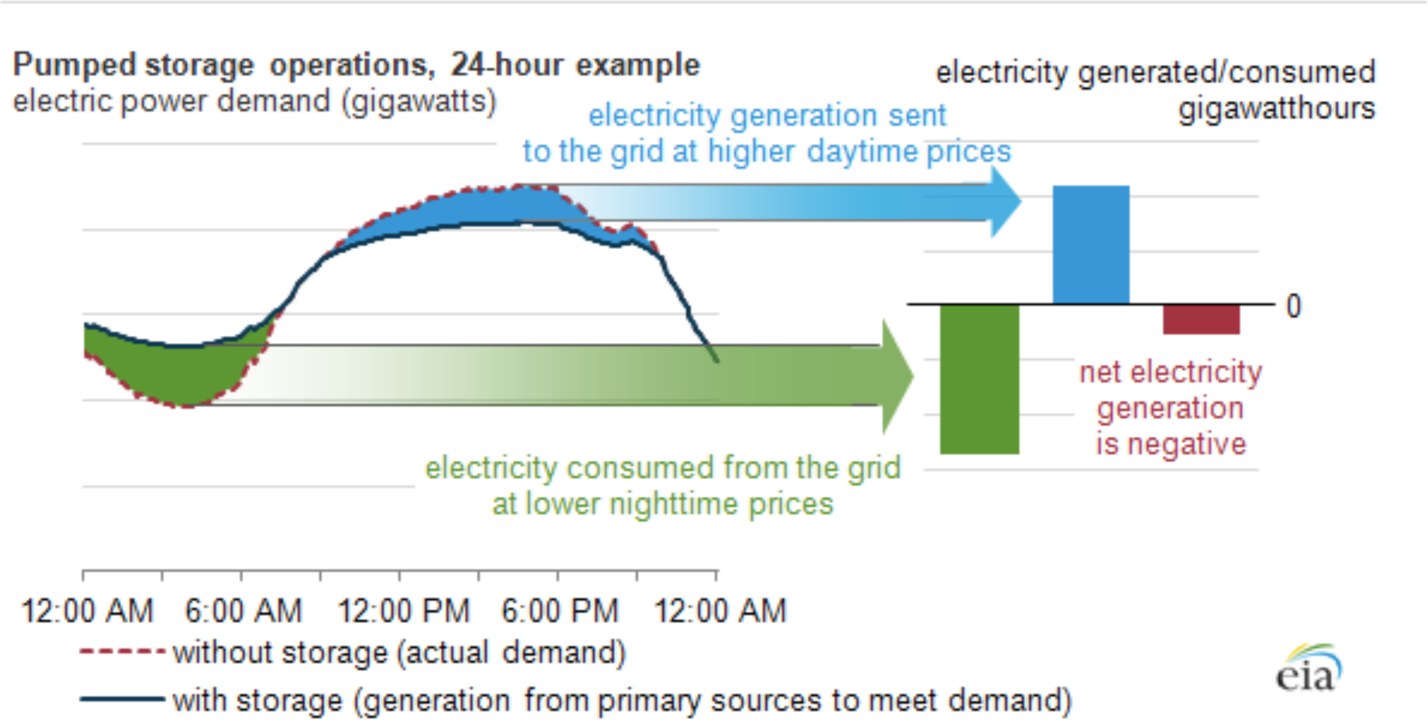
Technologies of interest in roundtrip efficiency context



Outline

- Focus areas for this potential program
- **Economics of long-duration storage, and proposed cost targets**
- Implications of our cost target:
- Technical approaches

Storage shifts energy between times of the day



The price differential provides revenue for the storage system

Sample economics for single-day shifting

Capital cost = ∑ (Discounted revenues over the project life)

= ∑ (Discounted per-cycle revenue) * (Total number of cycles)

Assume:

0.03 $/kWh-cycle (*<u>this is transformational!!</u>*)
1 cycle/day (roughly consistent with 8-h duration)
20 year project life
10% discount rate

Capital cost = ~100 $/kWh

Note: using only a fixed $/kWh-cycle ignores other sources of revenue, like capacity payments, so this is a "worst case" economic scenario.

Sample economics for single-day shifting

Capital cost = ∑ (Discounted revenues over the project life)

= ∑ (Discounted per-cycle revenue) * (Total number of cycles)

Assume:

0.06 $/kWh-cycle (*this is still impactful*)
1 cycle/day (roughly consistent with 8-h duration)
20 year project life
10% discount rate

Capital cost = ~200 $/kWh

Sample economics for multi-day shifting

Capital cost = $\sum$ (Discounted revenues over the project life)

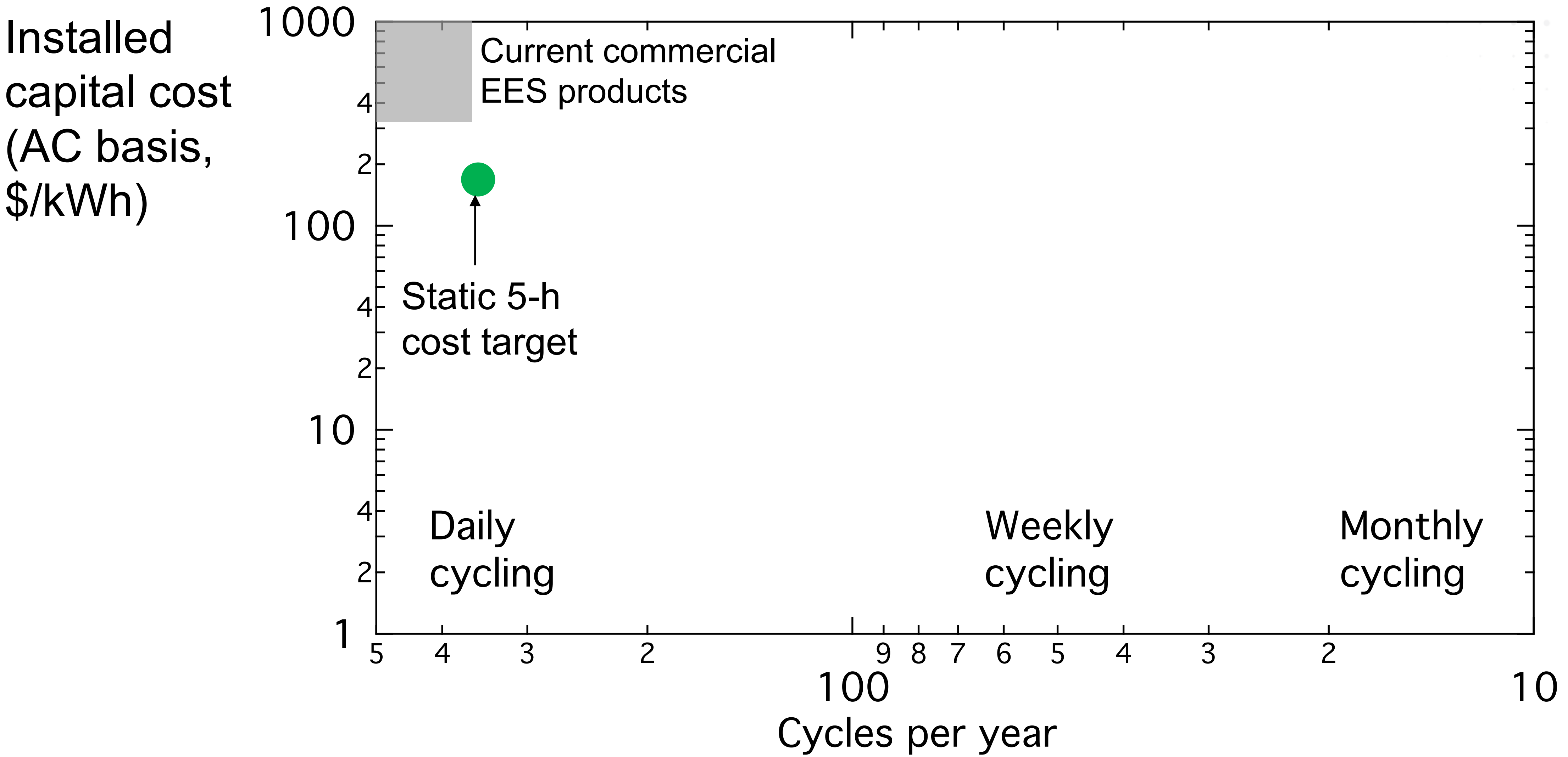
= $\sum$ (Discounted per-cycle revenue) * (Total number of cycles)

Assume:

0.03 $/kWh-cycle (*<u>this is transformational!!</u>*)
0.25 cycles/day (roughly consistent with **1 cycle per week**)
20 year project life
10% discount rate

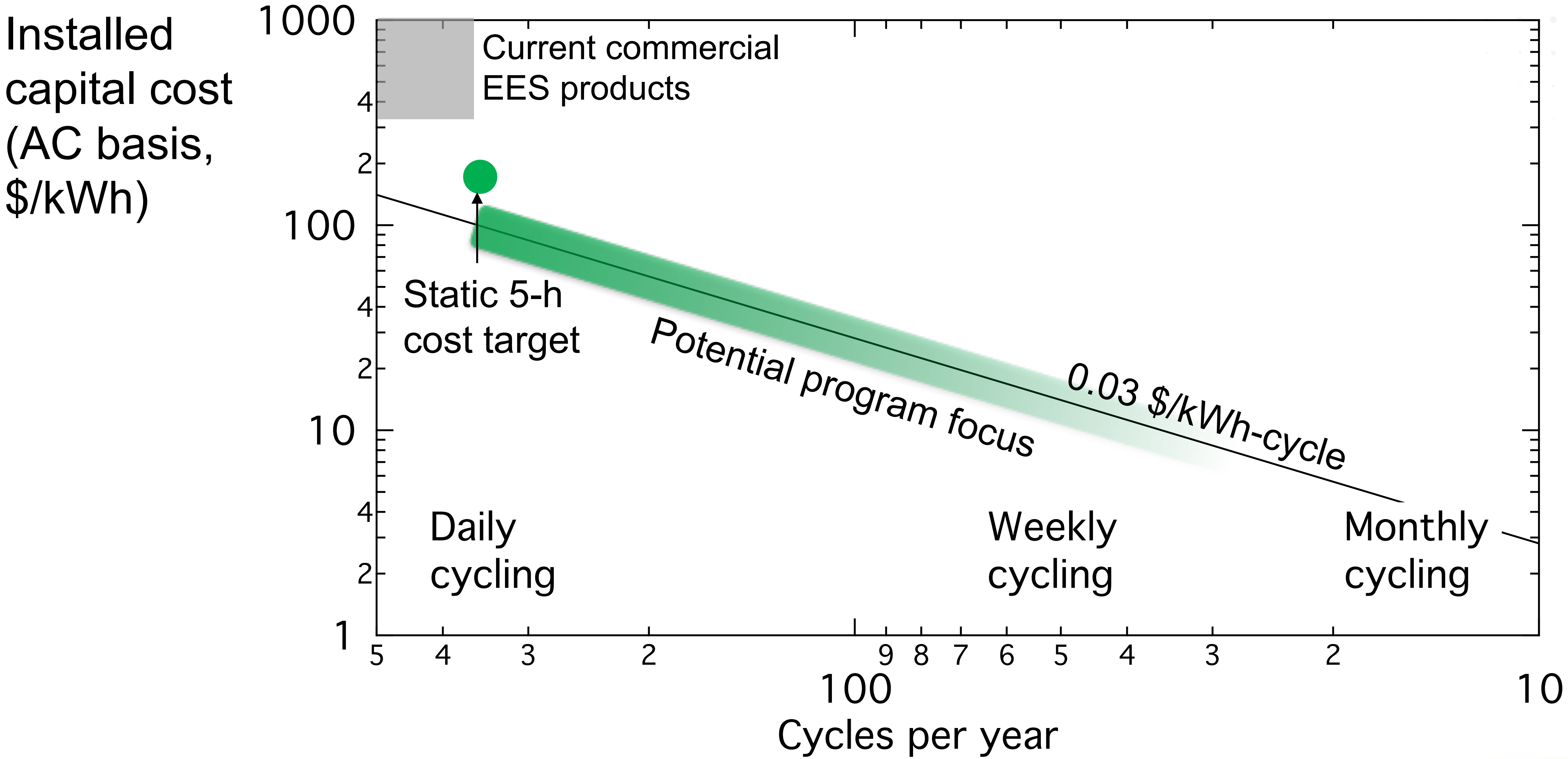
Capital cost = ~25 $/kWh

Today: a fixed-cycle energy time shift cost target



Assumes 20 year project life, 10% discount rate

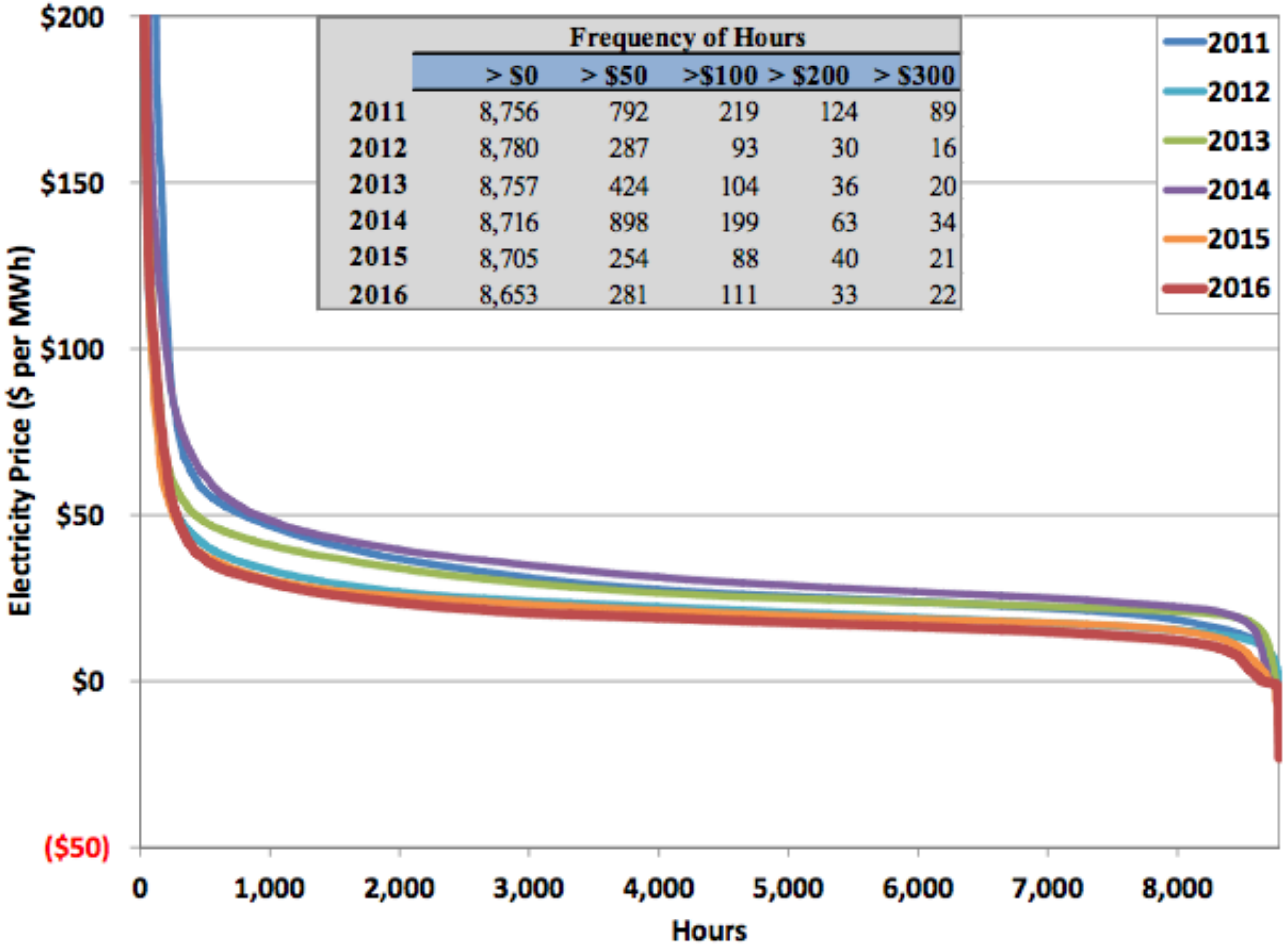
From a fixed-cycle to a variable cycle cost target function



Assumes 20 year project life, 10% discount rate

Why doesn’t the per-cycle cost change with cycles/year?

Figure 7: ERCOT Price Duration Curve

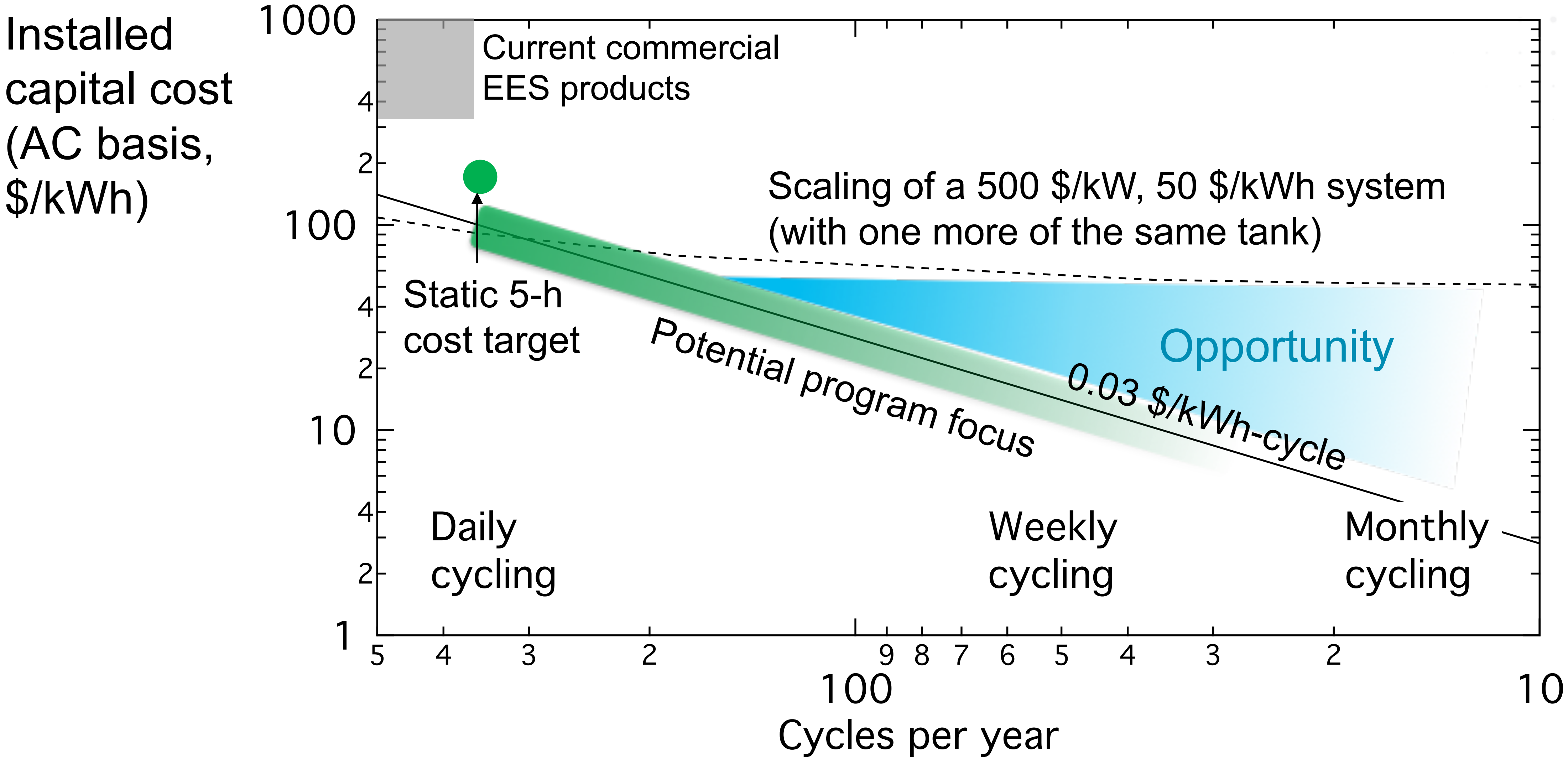


Frequency of Hours					
	> $0	> $50	>$100	> $200	> $300
2011	8,756	792	219	124	89
2012	8,780	287	93	30	16
2013	8,757	424	104	36	20
2014	8,716	898	199	63	34
2015	8,705	254	88	40	21
2016	8,653	281	111	33	22

- In ERCOT, >90% of hours clear at <0.05 $/kWh.
- As another data point, US peakers have a capacity factor of 7%.
- Wind and solar should not get more and more expensive as they move from 50% to 90% of annual energy.

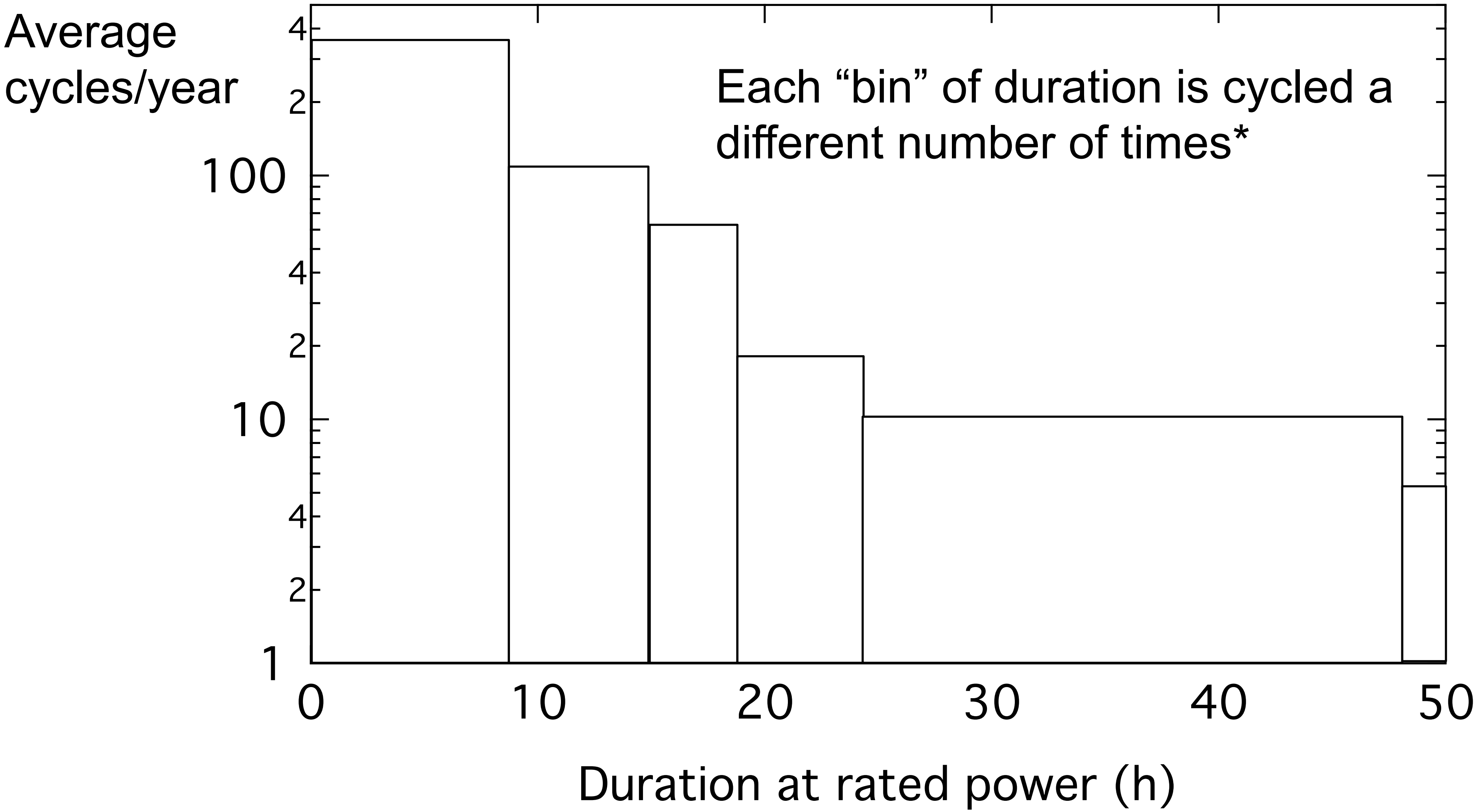
https://www.potomaceconomics.com/wp-content/uploads/2017/06/2016-ERCOT-State-of-the-Market-Report.pdf
Capity factor information: https://www.eia.gov/todayinenergy/detail.php?id=13191

There's a need for a fundamentally different scaling relation



Assumes 20 year project life, 10% discount rate

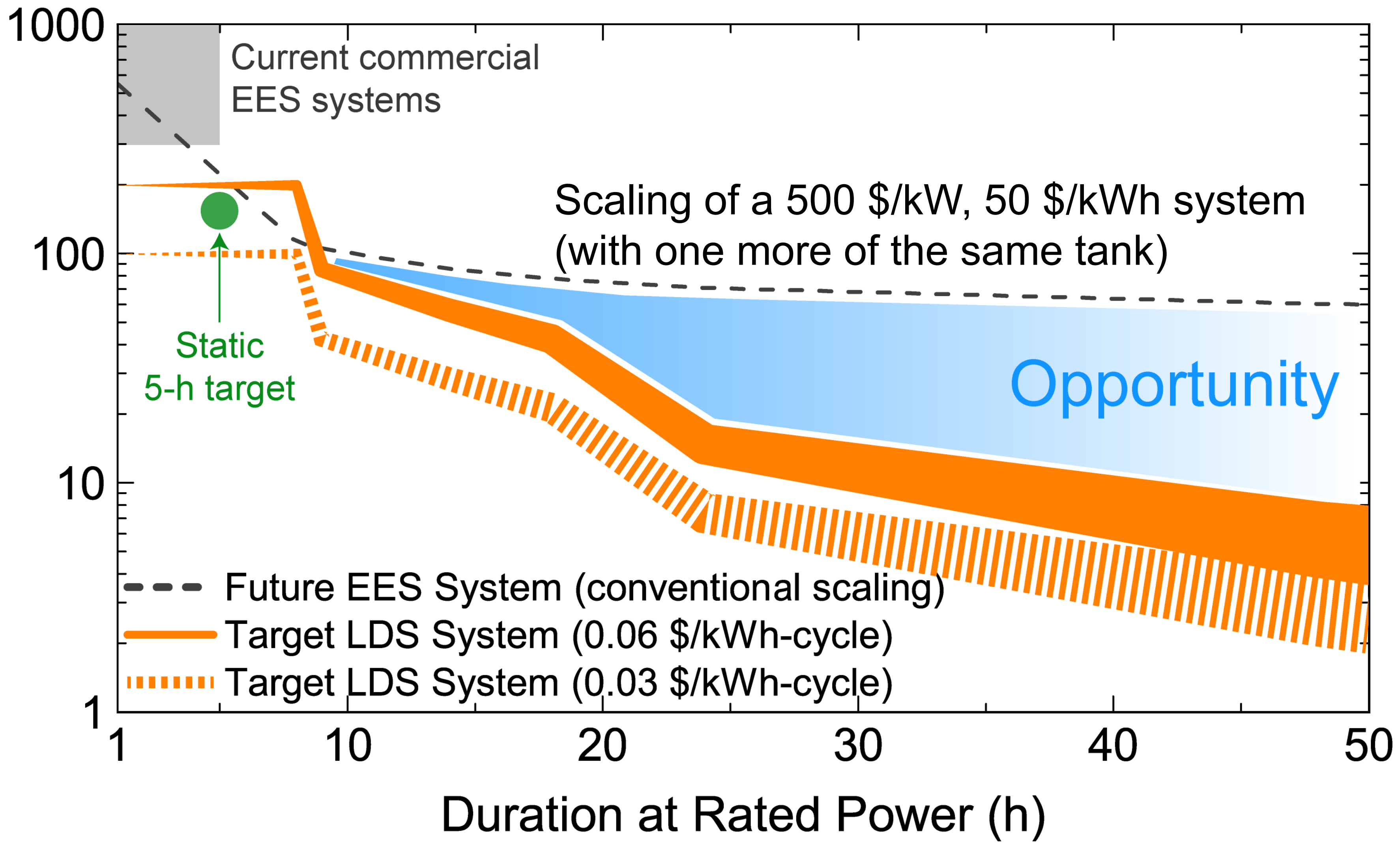
Translating cycles to duration depends on the use case



*Values shown are illustrative, not calculated for a real and specific case.

Capital cost targets vs. duration at rated power

Installed marginal capital cost (AC basis, $/kWh)



*Lines shown here are illustrative

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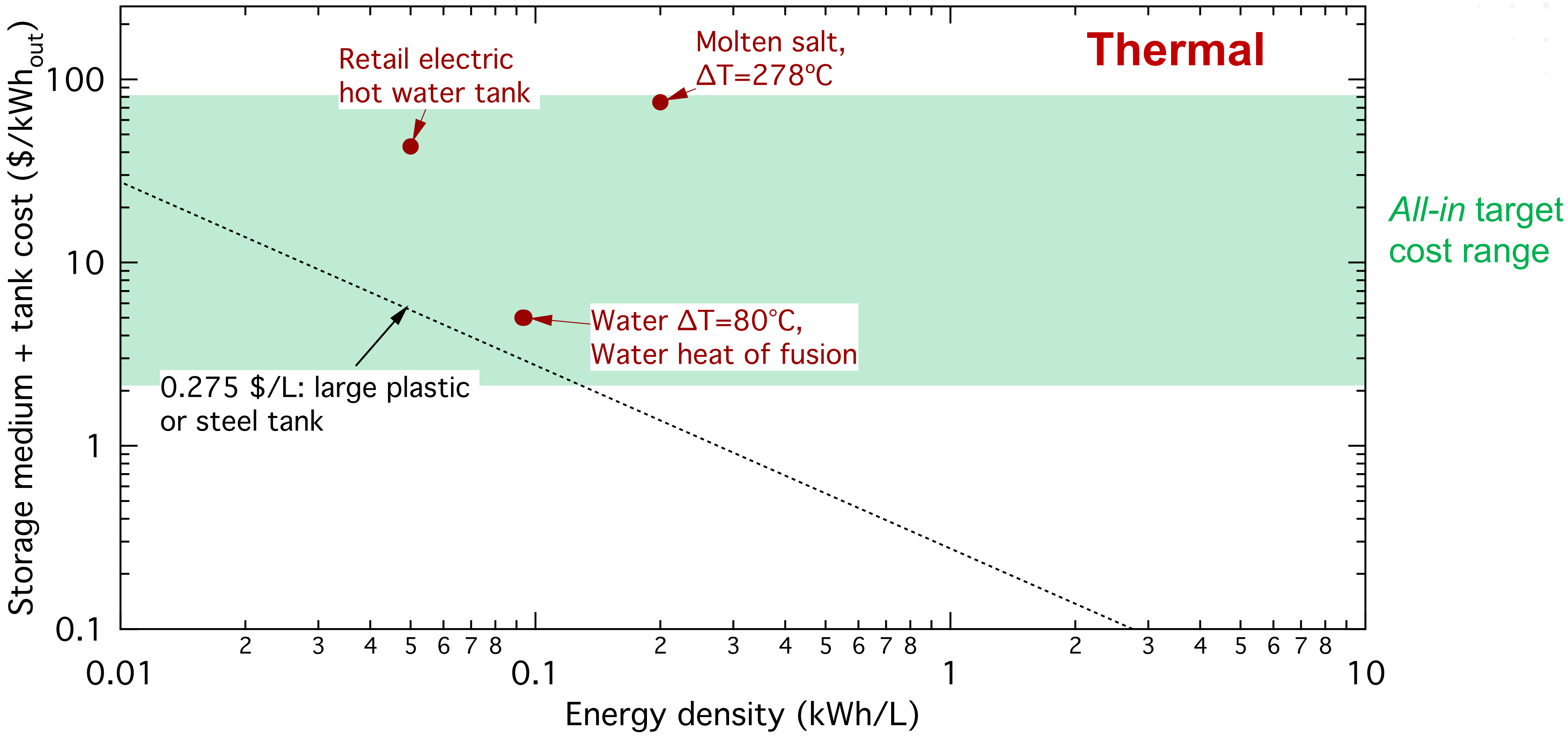
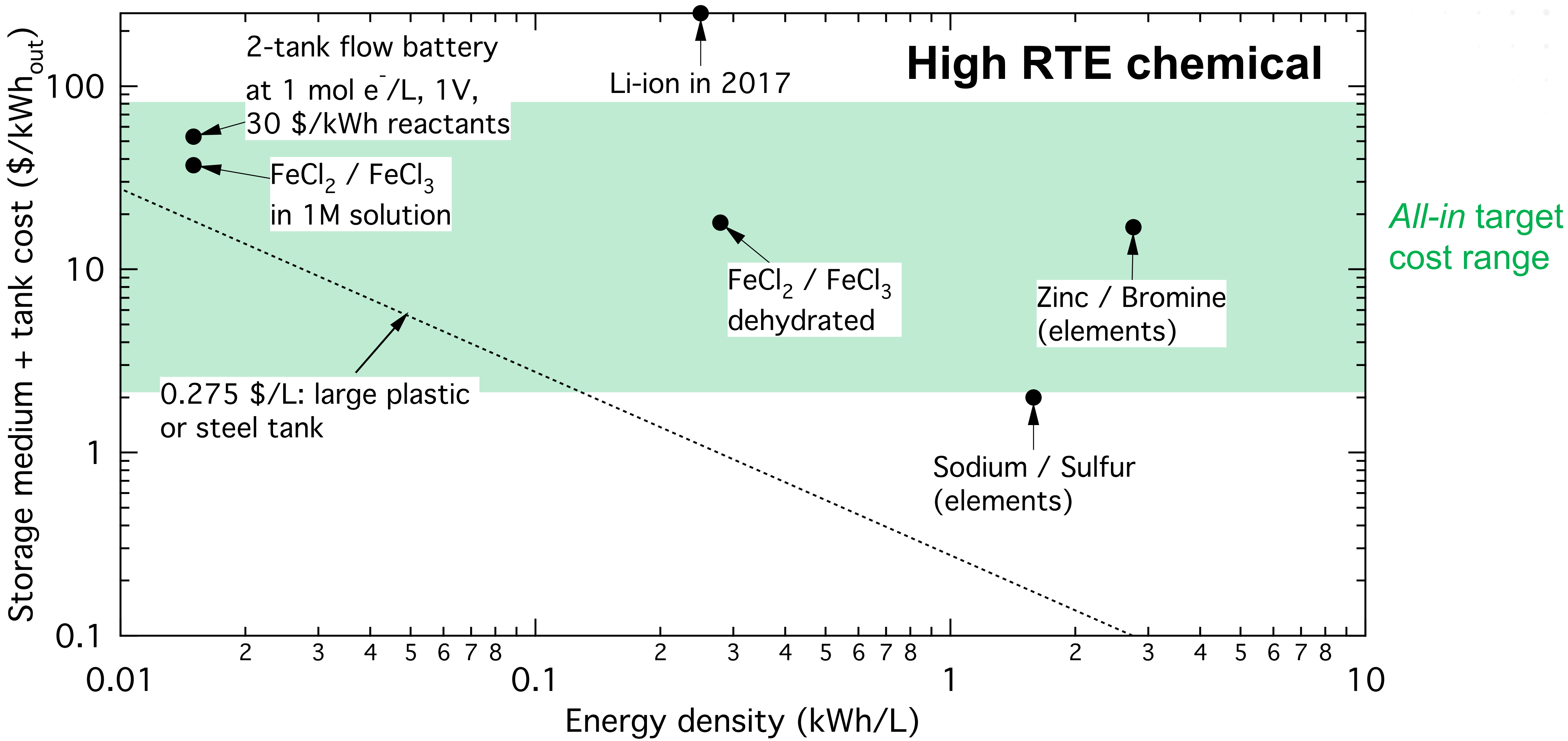
Outline

- Focus areas for this potential program
- Economics of long-duration storage, and proposed cost targets
- **Implications of the cost target for system design**
  - Energy density as applied to balance of plant
  - Safety and thermal conditioning
  - Energy storage medium
- Technical approaches

Energy density is a key for lowering BOP costs

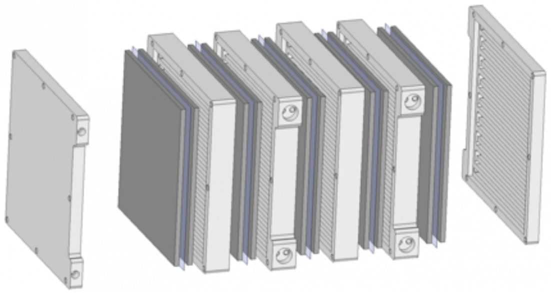


Energy density is a key for lowering BOP costs

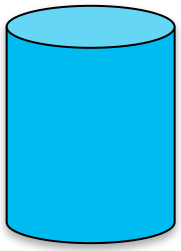


Energy density is a key for lowering BOP costs

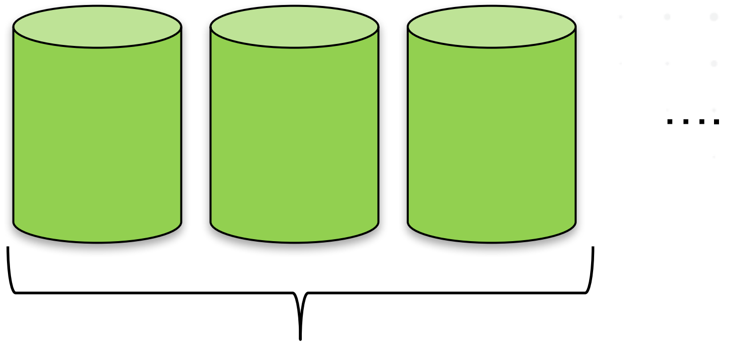
Power conversion stack



Storage tank for daily cycling



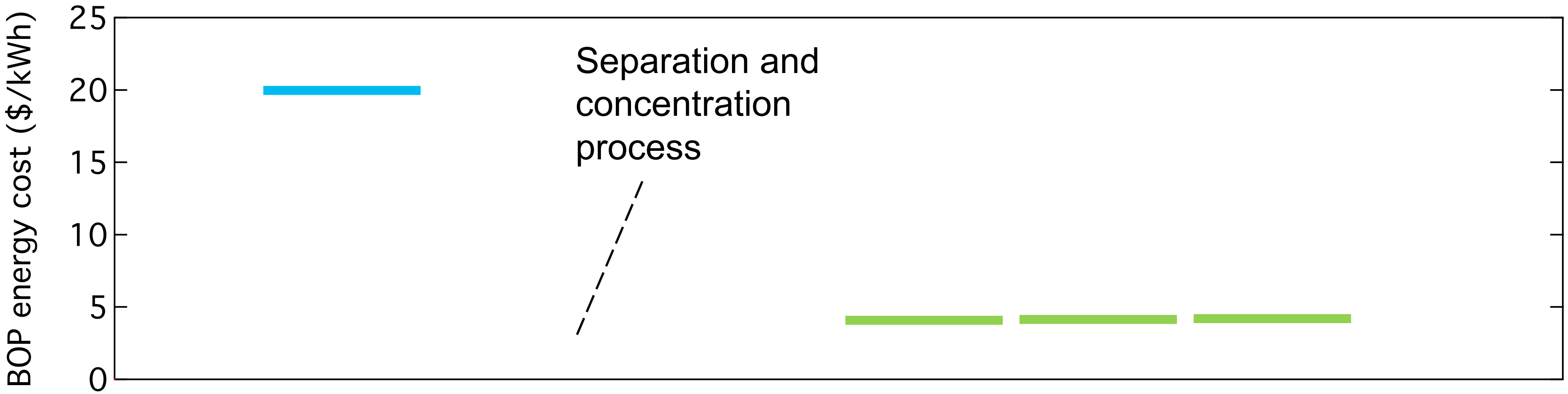
Storage tanks for beyond daily cycling



Fully dissolved reactants, 25 Wh/L

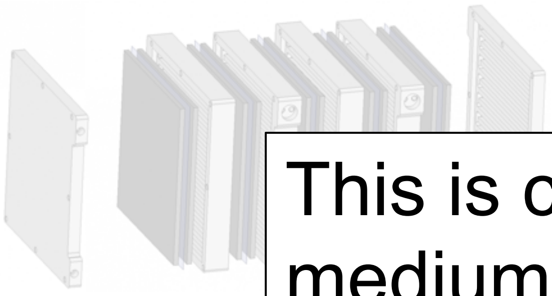
Concentrated reactants, >>100 Wh/L

Target <500 $/kW

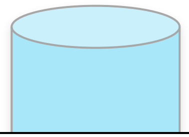


Energy density is a key for lowering BOP costs

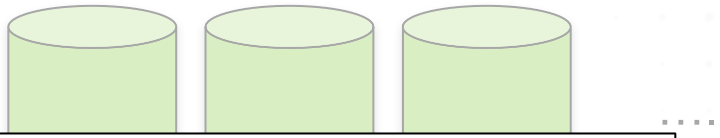
Power conversion stack



Storage tank for daily cycling



Storage tanks for beyond daily cycling

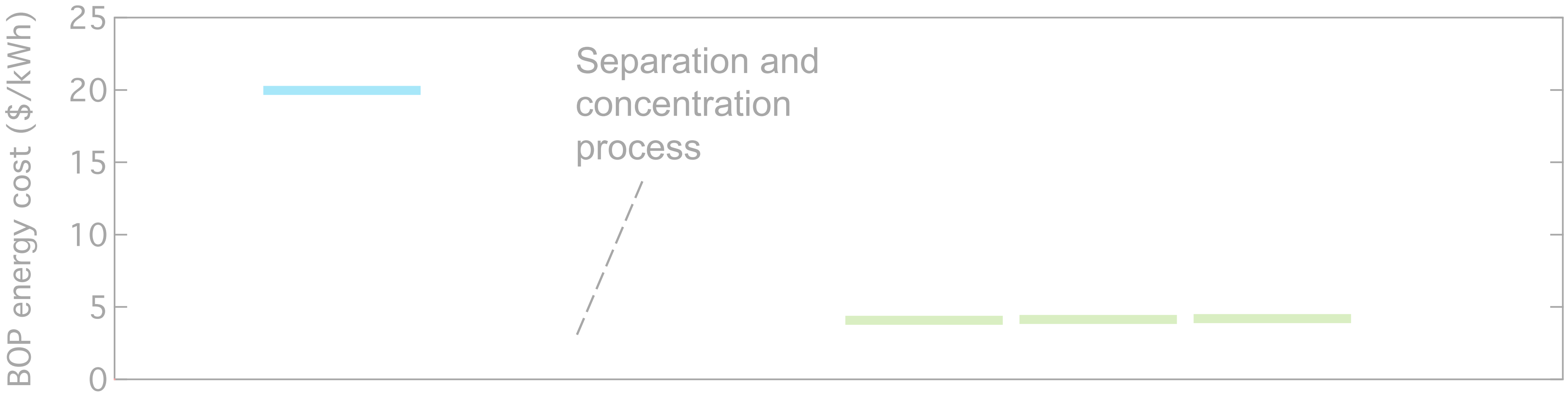


This is changing the properties of the energy storage medium *as a function of duration* to lower BOP costs.

Fully dissolved reactants, 15 Wh/L

Concentrated reactants, >100 Wh/L

Target <500 $/kW

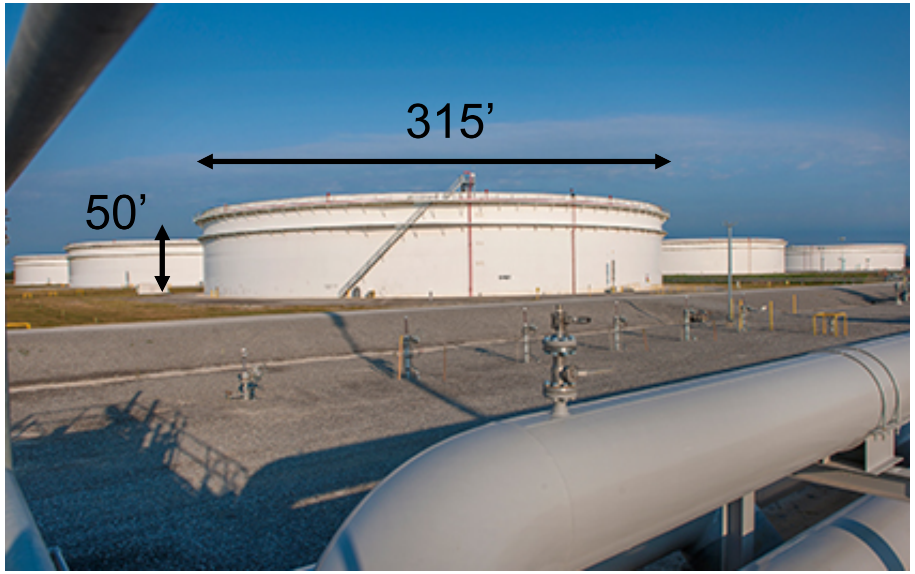


Higher energy density is essential for scaling to GWh size

450MW Natural Gas Combined Cycle Plant

=

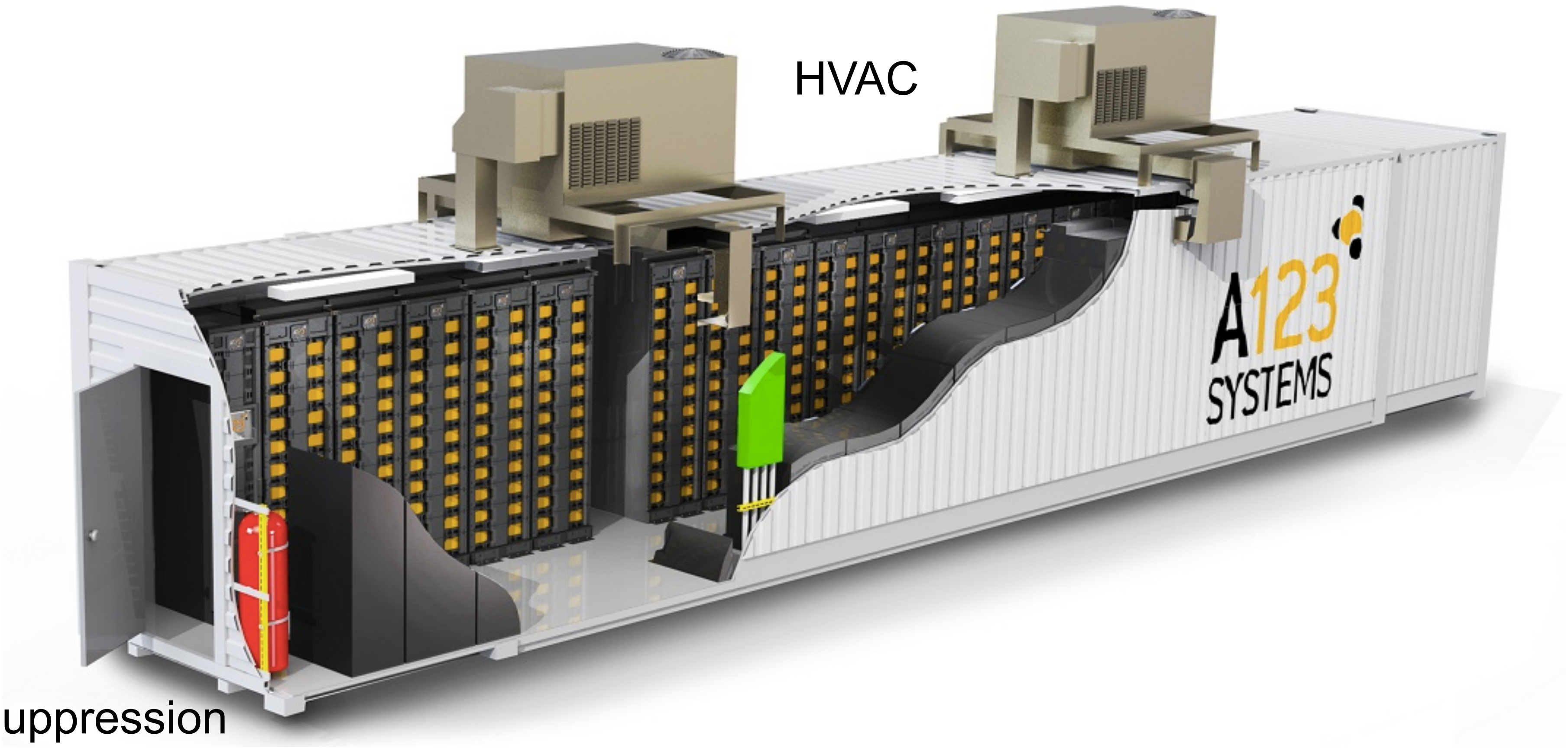
450MW/22,500MWh Flow Battery Storage



- At 25Wh/L, a 450MW, 50-hour battery would require 9 large crude storage tanks
- Two of these systems would require as much tank storage as a large crude oil terminal
- Louisiana Offshore Oil Port (LOOP): Port Fourchon, LA - 10m bbl tank capacity

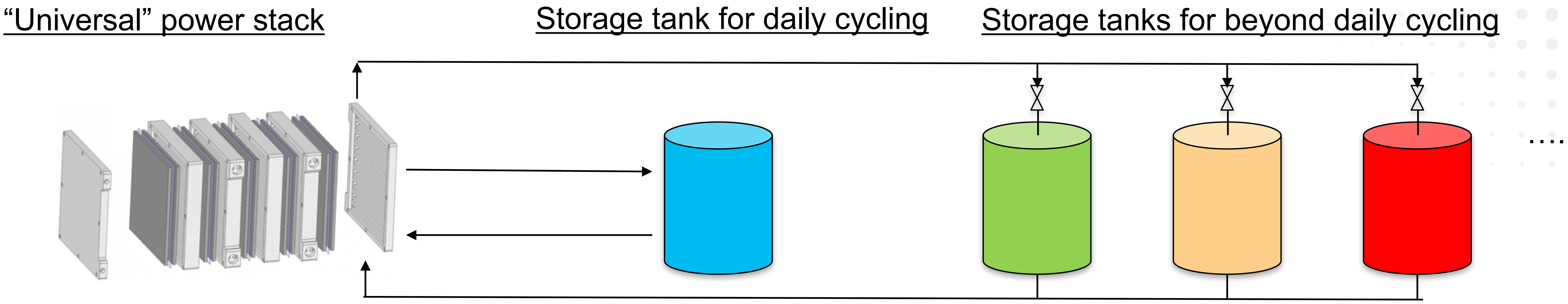
Safety and thermal conditioning are also key for lowering BOP

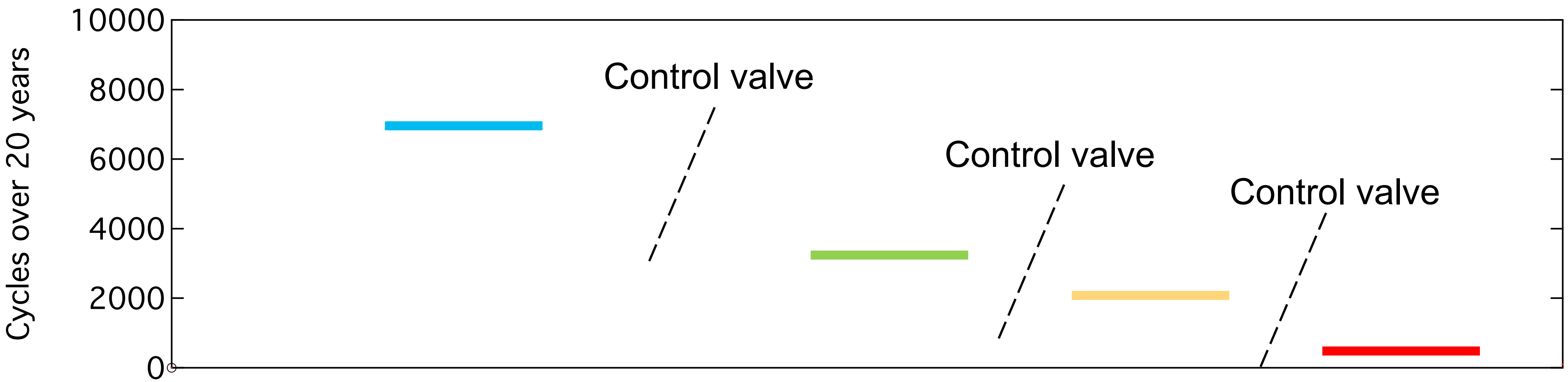
- Fire detection, suppression and HVAC cost ~15 $/kWh in Li-ion containers today.



Cost reference: ”Grid-scale energy storage balance of systems 2015-2020,” GTM.

There are also implications for energy storage medium design



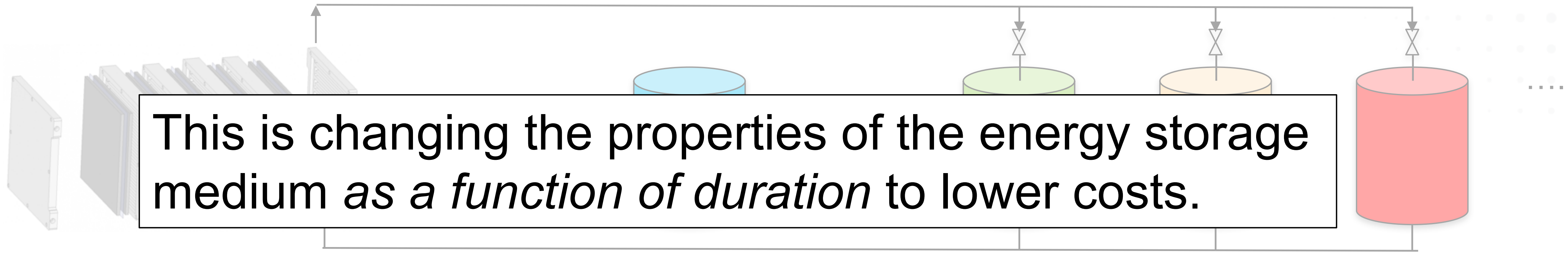


There are also implications for energy storage medium design

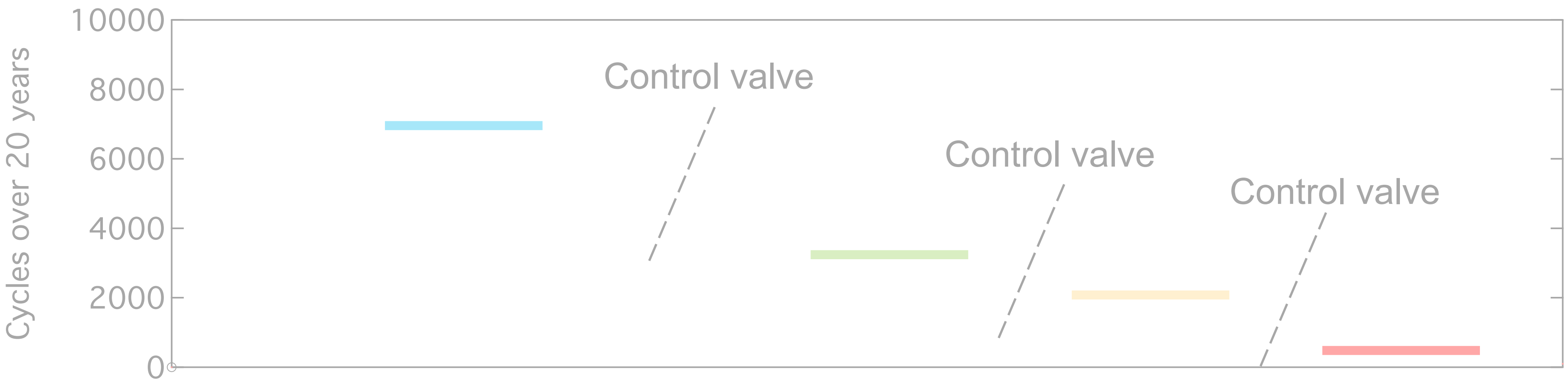
"Universal" power stack

Storage tank for daily cycling

Storage tanks for beyond daily cycling



This is changing the properties of the energy storage medium *as a function of duration* to lower costs.



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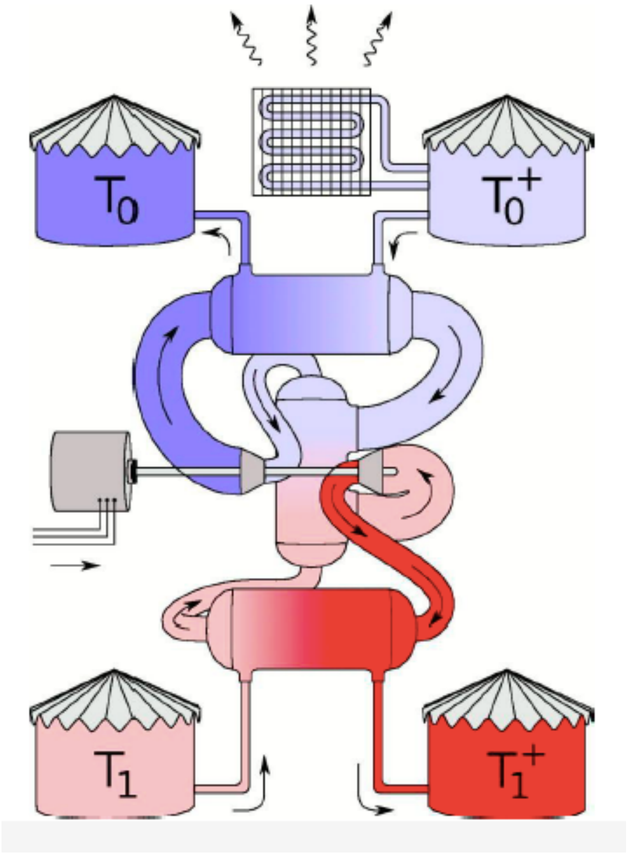
- **Technical approaches**

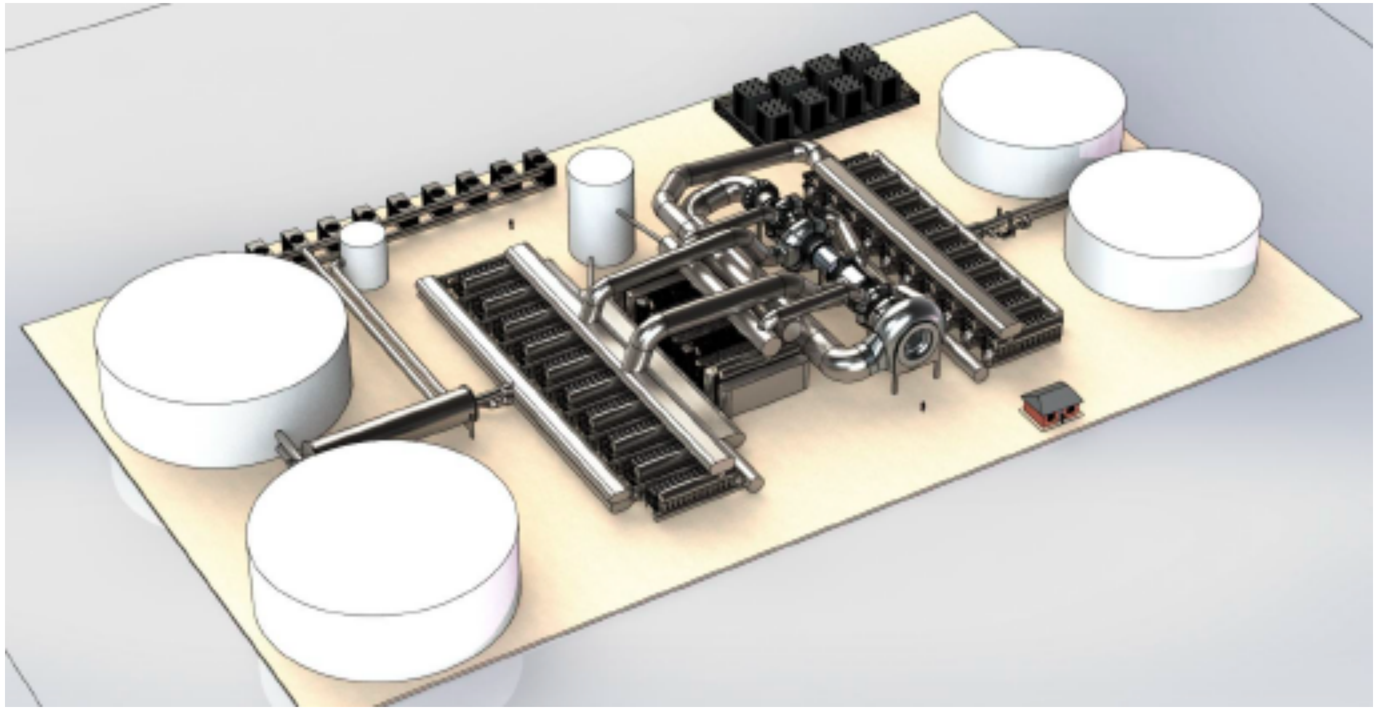
Technologies at this workshop: electrochemical

- Electrons in, electrons out.
  - Mostly flow systems, but non-flow technologies too

Technologies at this workshop: high-temperature thermal

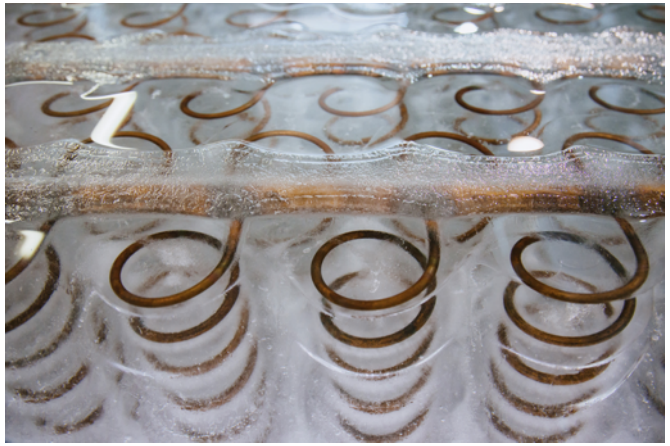
- Electrons in, electrons out.

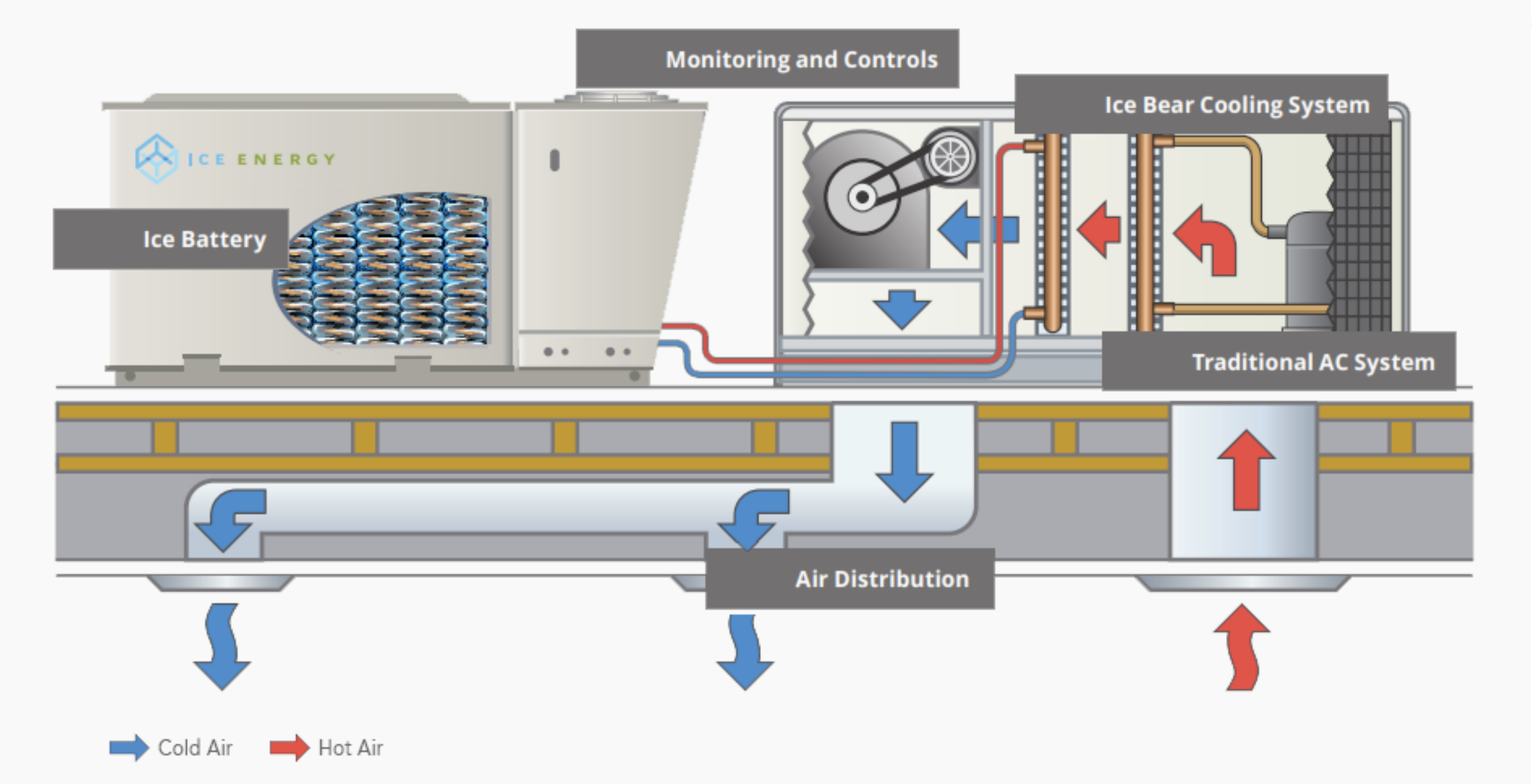




Technologies at this workshop: low-temperature thermal

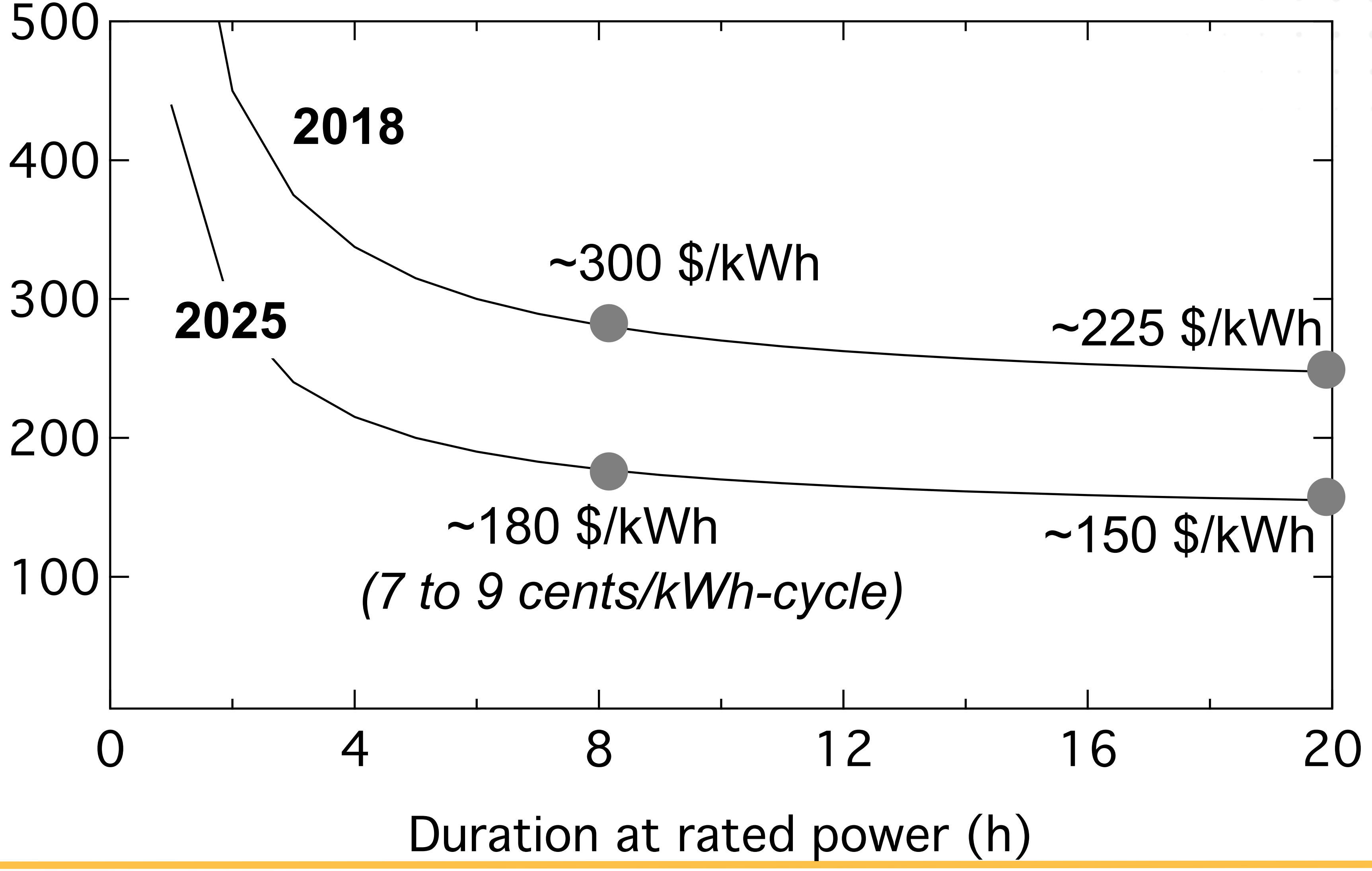
- Electrons in, thermal out (for direct integration with building thermal systems)
  – Most commercial activity today is cold; we are interested in systems that combine hot and cold storage in a single unit.





An important baseline for our discussions: Li-ion

Installed capital cost (AC basis, $/kWh)



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